doi:10.2489/jswc.64.1.53

Comparison of conventional and no-tillage corn and soybean production on runoff and erosion in the southeastern US Piedmont

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Abstract: Soil erosion on southern Piedmont soils remains a problem without application of sound conservation practices. This study was conducted to compare a no-tillage (NT) system with a conventional-tillage (CT) system in row-cropped land under natural rainfall conditions for six continuous years. Runoff and soil loss were continuously monitored from May 1995 to April 2001 from four erosion plots (7.3 m × 12.2 m [24 ft × 40 ft]) in CT and four plots in NT under a corn (*Zea mays* L.)–soybean (*Glycine max* L.) rotation in a Mecklenburg sandy clay loam and Enon clay loam (fine mixed, active, thermic, Ultic Hapludalfs) at a Piedmont location. Runoff was significantly less for NT than for CT in three study years; in the other three years no differences between treatments where found. The NT six-year runoff average was 33% lower than the six-year runoff average of CT. The tolerable soil loss level of 7.0 Mg ha^{-1} y^{-1} (3.1 tn ac^{-1} yr^{-1}) was exceeded in CT in four study years, while annual NT losses were always below 7.0 Mg ha^{-1} y^{-1} The six-year soil loss average was 74.7 Mg ha^{-1} (33.3 tn ac^{-1}) and 2.6 Mg ha^{-1} (1.2 tn ac^{-1}) for CT and NT, respectively. In CT, most of the soil lost during the six-year study period occurred during rain storms of high intensity. No-till was highly effective at protecting against soil loss during these rain storms.

Key words: conservation tillage—conventional tillage—crop residue—infiltration—no-till—runoff—soil erosion

Soil erosion is a major environmental problem in many regions of the United States. Explorers from the early 1700s described the southern United States Piedmont region as having "dark rich soils with transparent and clear streams" (Trimble 1974). Soil erosion increased as forest was converted to cropland by European settlers and exacerbated by farming practices used during the cotton-farming era (1820 to 1930 AD). Trimble (1974) estimated that from 1700 to 1970, the Piedmont lost an average of 18 cm (7 in) of topsoil as a result of agricultural land use.

Historically, land preparation techniques in the Piedmont have produced soil planting conditions similar to that achieved by today's conventional plow/disk practice. In general, the plow/disk practice still stands as the most common method of land preparation. The Conservation Technology Information Center (2004) reported for 2000 that 64% of the total acreage allotted to growing major crops in the Southeast used conventional tillage (CT) practices—i.e., practices that leave less than 30% of the surface covered with crop residue.

The erosion potential in a CT system is maximized by the high rate of soil detachment following tillage (Radcliffe et al. 1998). Two other factors that increase the erosion risk in the Piedmont are (1) high intensity rainfalls from scattered thunderstorms that occur in the cropping months of May, June, and July, and (2) the sloping nature of a significant amount of production fields.

An alternative to CT is to use a no-tillage (NT) system, which causes small soil disturbance during planting and leaves the soil in a consolidated condition with the soil surface covered by residues from previous crops. These soil conditions decrease particle detachment and prevent the formation of a surface seal. A porous soil surface is maintained, which favors infiltration (Cassel et al. 1995; Hargrove 1985), and the crop residue slows runoff allowing more time for water to infiltrate (Foster et al. 1985; Meyer 1985; West et al. 1991). Additionally, the decomposition of crop residue increases soil organic matter at the soil surface, which improves biological activity and increases soil structural stability (Golabi et al. 1988; West et al. 1991; 1992).

Information regarding the efficacy of NT to control erosion relative to CT in the Piedmont is limited. Rain simulation studies include those conducted by West et al. (1991, 1992), Sullivan et al. (2007), and studies under natural rainfall conditions are those by Langdale et al. (1979, 1992). Only two of these studies were mentioned in the summary of national soil erosion studies written by Zheng et al. (2004).

Because simulation studies cannot account for unexpected changes in rainfall and rainfall characteristics, their value, while useful, can be limited. For example, evaluations of how well NT systems can control soil erosion under natural rainfall is becoming increasingly important in the southeastern United States where the frequency of intense rain storms is predicted to increase, thus increasing the likelihood of producing significant runoff and erosion (Nearing et al. 2004). Long-term field assessments of no-till soil management systems are necessary to test quality performance under a combination of influencing factors that exist in a natural setting. This study was conducted to evaluate the effectiveness of a NT application for reducing runoff and soil erosion from row-cropped land relative to a CT system under natural rainfall conditions for six continuous years.

Materials and Methods

The experimental site was located at the North Carolina Agricultural and Technical State University Farm in Greensboro, North Carolina. The soil types at the site were Mecklenburg sandy clay loam and Enon clay loam (fine mixed, active, thermic, Ultic

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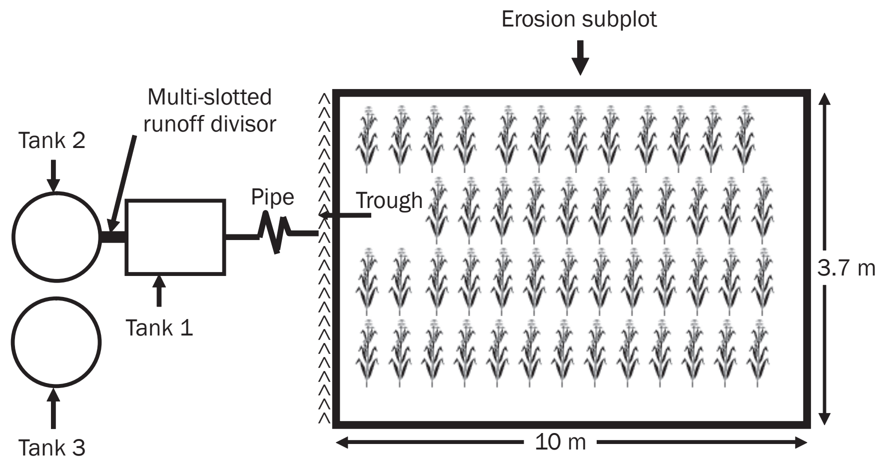
Hapludalfs). The sand, silt, and clay content of the upper 20-cm (8-in) surface horizon were respectively 59%, 22%, and 19% for the Mecklenburg soil and 42%, 29%, and 29% for the Enon soil. The average annual rainfall for the region ranged from 1,016 mm to 1,397 mm (40.0 in to 55.5 in). The site had a 30-year cropping history of corn (*Zea mays* L.) and soybean (*Glycine max* (L.) Merr.) cultivated under plow/disk tillage.

The experimental design was a randomized complete block with NT and CT treatments replicated four times. To block the variability due to soil type, two replications were positioned on Mecklenburg soil and the other two on Enon soil. The eight experimental plots (4 blocks × 2 treatments) were 7.3-m (24-ft) wide and 12.2-m (40-ft) long to accommodate eight crop rows that ran parallel to the slope and spaced 0.9 m (3 ft) apart. Conventional tillage involved chisel plowing to 25.4 cm (10 in) with shanks at 30.5 cm (12 in) spacing and disking twice prior to planting. No-till planting was performed using a double-disk opener assembly following a ripple coulter. The one pass each year with the planter and the harvest combine were the only traffic equipment used in both treatments. Foot and machinery traffic were controlled in NT and CT for the duration of the study by confining it to alternating interrow middles spaced 1.8 m (72 in) apart. No winter cover crops were grown in NT or CT.

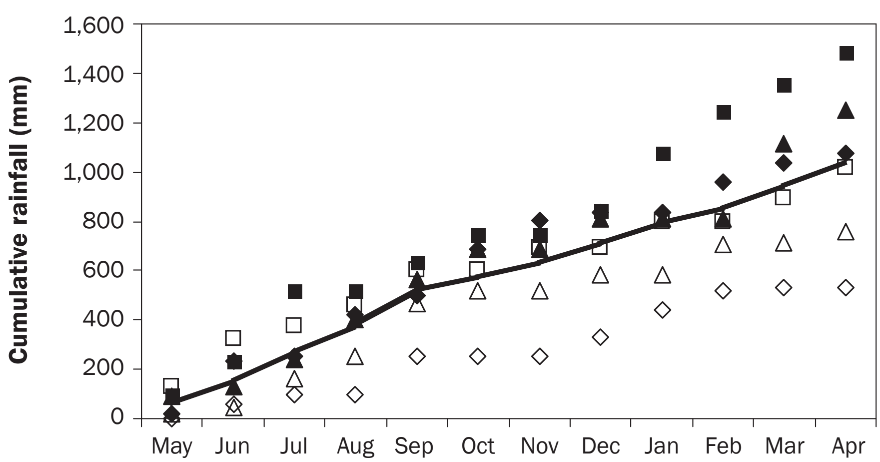
Tillage treatments were first implemented in 1994. Crops grown were soybeans in 1994, 1997, 1998, and 2001, and corn in 1995, 1996, 1999, and 2000. On corn years, plowing in CT was done in late April, disking and planting was done in early to mid-May, and harvest was generally in late October, with cornstalks being chopped in early November. On soybean years, plowing in CT was done in early to mid-May, disking plus planting was done in late May and harvest was in mid-November. Corn and soybean varieties were Pioneer 3156 and Pioneer 9692, respectively. Measurements of surface crop residue cover made at planting using the line-transect technique (Shelton et al. 1993) ranged from 84% to 96% and averaged 91% in NT, and ranged from 5% to 13% and averaged 9% in CT. Erosion subplots were installed immediately after planting, and all farming practices thereafter were done manually to avoid removal of erosion plot metal borders. Fertilizer was banded 15.2 cm (6 in) away from corn and soybeans rows at rates recommended for optimum production by the North Carolina Department of Agriculture. Weed control was achieved by spot spraying Roundup Ultra (Glyphosphate: N-[phosphonomethyl] glycine).

Figure 1
Erosion Sub-plot schematic.



Note: Erosion subplots enclosed four of eight rows in the 7.3-m wide by 12.2-m long experimental plots.

Figure 2
Cumulative rainfall during study years 1995 to 1996 (◆), 1996 to 1997 (▲), 1997 to 1998 (■), 1998 to 1999 (◊), 1999 to 2000 (Δ) and 2000 to 2001 (□) compared to the cumulative 58-year average (solid line).



Uniform slope gradients existed in plots within replications but varied between replications ranging from 3.8% to 6.2%. Erosion subplots were first installed immediately after tillage and planting in May 1, 1995, and were used to monitor runoff and soil loss for six years until April 30, 2001. Sheet metal borders were forced into the ground to form the 3.7-m (12-ft) wide by 10.0-m (33-ft) long erosion subplots that encompassed four crop rows (figure 1). Runoff flowed into a trough at the subplot lower side and flowed through a pipe into a collector tank. After this tank filled, runoff flowed through a multi-slotted divisor (Reyes et al. 1999), and one ninth of the flow was collected in two other adjacent tanks. The divisor was fabricated using the design described in Brakensiek et al.

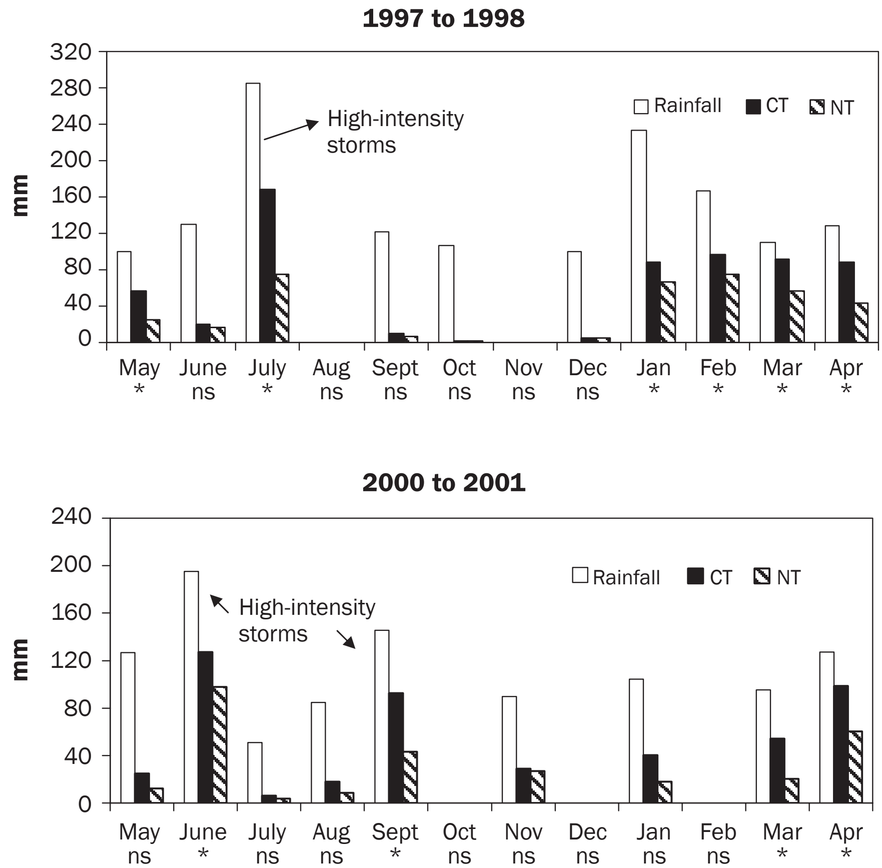
(1979). The total runoff collection capacity of 100 mm (3.9 in) was not exceeded during the six years of runoff collection. Runoff volume and sediment concentration were measured from each tank mostly after each rainfall event, but occasionally one sampling included runoff from multiple rainfall events. Sediment concentration was determined by gravimetric analysis from 1-L (2.1-pt) samples collected while stirring and thoroughly suspending the sediment in the runoff tanks. Precipitation data were collected using an automated weather station located less than 1 km (0.6 mi) from the plots. The rainfall intensity percentage method (Reyes et al. 1993) was used to measure rainfall intensities at 5-minute intervals.

Soil core samples were collected immediately after a series of high intensity rain storms that occurred in July 1997 and June and September 2000 to determine soil loss height equivalents. Two soil cores (7.6-cm in diameter by 7.6-cm in length) (3 in × 3 in) were collected per plot from the surface 7.5 cm (3 in) of non-traffic row middles using an Uhland apparatus (Blake and Hartge 1986). Cores were oven dried at 105°C (221°F) to determine bulk density (Grossman and Reinsch 2002). The soil loss height during these periods of high intensity rainfall was calculated using the amount of soil lost and the soil bulk density.

Soil aggregates of size 2.00- to 4.75-mm (0.08- to 0.19-in) in diameter were collected from each plot on May 1, 2001, (year 6) in increments of 2.5 cm (1 in) to a depth of 7.5 cm (3 in) and from 7.5 to 15 cm (3 to 6 in) and 15 to 30 cm (6 to 12 in) depths. Aggregates were air-dried, and wet aggregate stability was measured by a wet sieving technique (Arshad et al. 1996). Aggregates were evenly distributed on a 2.00-mm (0.08-in) sieve to form a single layer and were oscillated in deionized water twenty five times in a one minute period. Aggregates that remained in the sieve were oven dried and weighed to determine the percent stable fraction.

Statistical analyses of monthly and yearly runoff and soil loss totals were conducted using statistical analysis systems (Statistical Analysis Systems Institute 2001) and analysis of variance procedures for a randomized complete block design. The critical level for null hypothesis rejection was 5% (α = 0.0500).

Figure 3
Monthly runoff totals for conventional tillage (CT) and no tillage (NT) treatments during the 1997 to 1998 and 2000 to 2001 study years



Note: For each month, a significant difference (p = 0.0500) between CT and NT treatment means is denoted as "*" while non-significance is indicated as "ns."

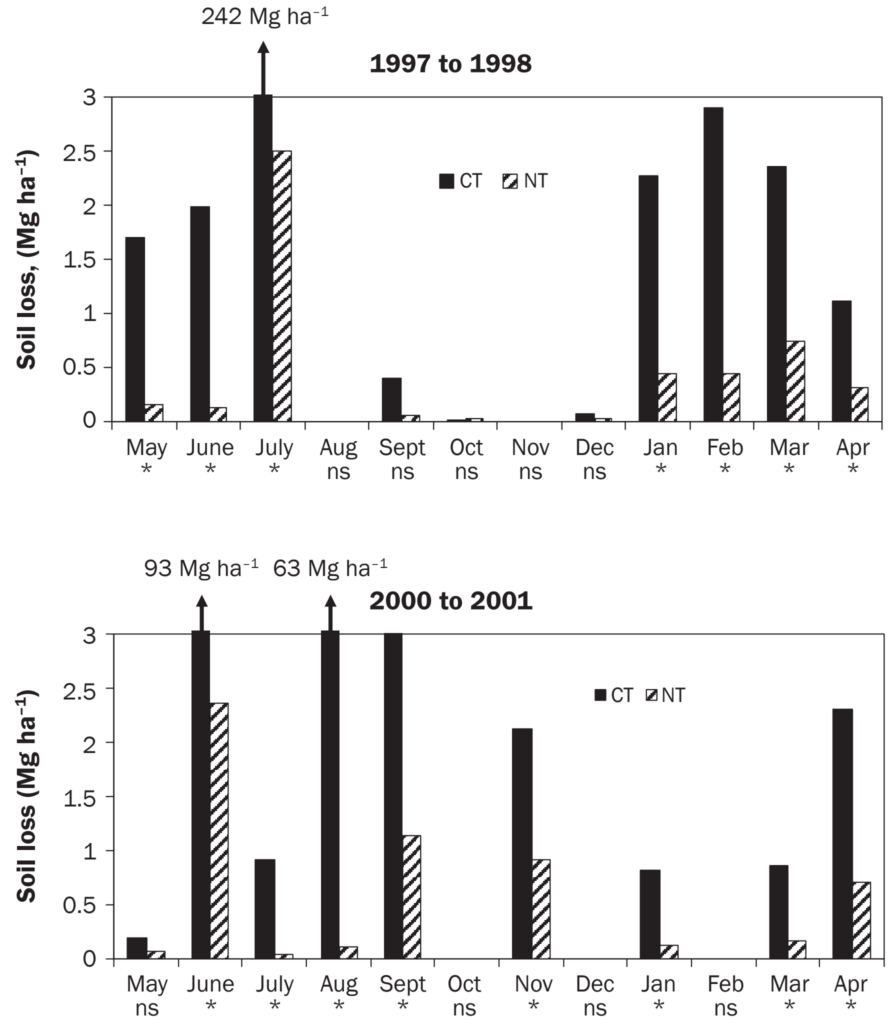
Results and Discussion

Average annual precipitation during the 6-year study period was 1,018 mm (40.1 in), 27 mm (1.1 in) below the 58 year annual average (figure 2). Precipitation was above average in 1997 to 1998, near average in 1995 to 1996, 1996 to 1997, and 2000 to 2001, slightly below average in 1999 to 2000, and well below average in 1998 to 1999.

Only monthly runoff and soil loss data for years 1997 to 1998 and 2000 to 2001 are shown (figures 3 and 4) because in these two years a few highly erosive storms caused most of the soil erosion in the six-year study period. Also, with the exclusion of the data generated by these storms, monthly trends within treatments and yearly treatment differences were similar for all years.

Runoff was greater in CT than in NT in most months of the year, including the non-growing season (figure 3). Each year, the CT soil surface sealed quickly after tillage and following the first few storms in May and June. The formation and nature of the surface seal formed in CT was not quantified, but the condition of the soil surface was observed during frequent site visits. As the seal developed, we observed an increase in surface runoff and eroded sediment mostly along traffic lanes (figure 5a). Increased runoff, partly as a result of surface sealing and partly as a result of high intensity rainfall, is common in many Piedmont soils and has been found to influence soil erosion rates (Bradford et al. 1987; Zhang and Miller 1996). The sealed condition remained in CT until tillage in May of the following year. By contrast, the lower runoff amounts with NT suggest greater infiltration due to the influence of crop residue protecting against surface sealing and slowing runoff. Also favoring infiltration in NT were

Figure 4
Monthly soil loss totals in conventional tillage (CT) and no tillage (NT) treatments during the 1997 to 1998 and 2000 to 2001 study years.



Note: For each month, a significant difference (p = 0.0500) between CT and NT treatment means is denoted as "*" while non-significance is indicated as "ns."

many openings at the soil surface of burrows made by earthworms and other soil animals. Another factor favoring infiltration in NT was increased soil aggregation, a condition known to develop in this biologically active tillage system (Hussain et al. 1991; Langdale et al. 1992; Rhoton et al. 2002; West et al. 1991). Increased soil aggregation has a two-fold effect, and both favor infiltration: (1) increased aggregation increases soil porosity, and (2) formation of water-stable aggregates reduces surface sealing. Measurements of aggregate stability in this study showed that NT had a higher percentage of water-stable aggregates than CT in the upper 7.5 cm (3 in) (table 1). The average percent stability for the upper 7.5 cm (3 in) was 10.2% higher in NT. We point out that these measurements were made at the conclusion of the study period and that differences in water stability may not have been as large during the first few years of the study.

As noted previously, periods of multiple storms with high intensity and long return periods occurred in July 1997 and in June and September of 2000. The rainfall characteristics of the storms that occurred in July 1997 (table 2) depict the nature of these storms. The total rainfall received from the five July 1997 storms was 243 mm (9.6 in). Almost half of this rainfall (47%) fell at intensities greater than 80 mm h^{-1} (3 in hr^{-1}), and about one third (34%) fell at intensities greater than 120 mm h^{-1} (4.7 in hr^{-1}). The two most intense storms occurred on July 22nd, which lasted two hours with 116 mm (4.6 in) of rainfall, and the July 29th one-hour event with 67 mm (2.6 in) of rainfall. The return periods of these rainstorms were respectively 100 and 50 years (Bonnin et al. 2004).

Monthly soil loss data for 1997 to 1998 and 2000 to 2001 (figure 4), illustrates treatment differences and monthly trends that were similar from year to year. In general, in the 72 months of measurements, CT had losses exceeding 2 Mg ha^{-1} (0.9 tn ac^{-1}) in 13 months, losses between 1 and 2 Mg ha^{-1} (0.45 and 0.9 tn ac^{-1}) in 7 months, and losses below 1 Mg ha^{-1} (0.45 tn ac^{-1}) in 52 months. In NT, losses were greater than 2 Mg ha^{-1} in 2 months, between 1 and 2 Mg ha^{-1} in 3 months, and less than 1 Mg ha^{-1} in 67 months of the 72 months comprising the study period.

Despite the almost 100% surface cover from fall harvest residue, losses exceeding 2 Mg ha^{-1} (0.9 tn ac^{-1}) occurred in CT in some months between December and April (figure 4). It is likely that particle detachment by runoff was the major cause for this off-cropping season erosion. Through frequent site visits during rainstorm events, we concluded that this type of erosion occurred in CT during most periods. We based this conclusion on the following time order of observations: (1) rapid sealing of the soil surface after tillage, (2) decreased particle detachment by raindrop impact due to the presence of a seal and rainfall interception by the growing crop canopy, and (3) continued particle detachment during the off-cropping period by surface runoff. Raindrop impact was a major source of soil particle detachment in CT, while the soil surface remained uncovered by either residue or the crop canopy—i.e., the time period between tillage and full canopy closure.

Figure 4 also shows the extremely high soil losses that occurred in CT during the months of July 1997, June 2000, and September 2000. In these three months, CT soil losses were 242 Mg ha^{-1} (107.9 tn ac^{-1}), 93 Mg ha^{-1} (41.5 tn ac^{-1}), and 63 Mg ha^{-1} (28.0 tn ac^{-1}), respectively. In NT the highest soil loss was 2.5 Mg ha^{-1} (1.1 tn ac^{-1}) in July 1997. The magnitude of difference in soil loss between the two treatments in these three months reflects how structurally stable the NT soil matrix was relative to that in CT.

Evidence of NT's superior ability to capture rainfall is shown in figure 5. Both photos were taken on June 12, 2001, immediately after 38 mm (1.5 in) of rainfall. The CT photo shows an almost completely sealed soil surface, the occurrence of runoff (free water at the surface) and zones with washed sediment in wheel-traffic areas. In contrast, the NT photo shows a soil surface almost entirely covered by residue, and no evidence of runoff or washed sediment. The runoff and soil loss generated by the 38-mm (1.5-in) rainfall were respectively 8.9 mm (0.35 in) and 1.9 Mg ha^{-1} (0.84 tn ac^{-1}) for CT, and 0.44 mm (0.02 in) and 0.1 Mg ha^{-1} (0.04 tn ac^{-1}) for NT. West et al. (1991) support our findings, and summarize the following conditions in NT as major causes for reduced runoff and soil loss over CT: (1) a significant accumulation of crop residue covering the soil surface, (2) a consolidated soil condition, and (3) higher soil structural stability.

Figure 6 shows runoff and soil loss totals for each of the six study years. Runoff was significantly less for NT than CT in three of the six years. The NT six-year runoff average was 33% lower than that of CT. Larger differences between treatments were found with the soil loss data than with the runoff data (figure 6). In four of the six study years, the tolerable level of 7.0 Mg ha^{-1} (3.1 tn ac^{-1}) for the research site location (Stephens 1977) was exceeded in CT whereas in NT the tolerable level was never exceeded. The six-year average soil loss for NT was 2.6 Mg ha^{-1} (1.2 tn ac^{-1}) while CT averaged 74.7 Mg ha^{-1} (33.3 tn ac^{-1}).

The total soil lost in CT during the six-year period was 448.2 Mg ha^{-1} (199.9 tn ac^{-1}). Eighty nine percent of this loss occurred during the highly erosive storms that occurred in the months of June 1997, June 2000, and September 2000. Calculations of the depth of top soil lost using soil bulk density data equaled 2.90 cm (1.1 in) in CT and 0.04 cm (0.01 in) in NT (table 3). The CT loss of 2.90 cm (1.1 in) of soil equals a 14.5% loss of the 20 cm (7.9 in) Ap horizon.

Excluding all highly erosive storm soil loss data from the calculation of soil loss gives an annual average value for CT of 8.4 Mg ha^{-1} (3.7 tn ac^{-1}), slightly exceeding the tolerable 7.0 Mg ha^{-1} (3.1 tn ac^{-1}) value. Collectively, the six-year data indicates that highly erosive storm events are primarily responsible for generating soil losses in Piedmont CT systems that exceed tolerable levels. On the other hand, NT is highly effective against soil erosion during high intensity storm events; it restrains particle detachment, lowers runoff volume, and maintains soil losses below the tolerable level.

Using erosion data collected from 1940 to 1959 for development of the universal soil loss equation, Langdale et al. (1992) studied the occurrence of these low return-frequency storms in the Piedmont and their accelerated erosive effects in CT systems. Based on their findings, they discuss the importance of using conservation tillage to prevent excessive erosion during these storm events. The importance of implementing soil conservation management is also emphasized in the Nearing et al. (2004) report on the implications of climate change on soil erosion rates. All the studies in this review suggested that increased rainfall amounts and intensities will lead to greater rates of erosion in several regions of the United States. Their predictions included a reduction in the number of days of precipitation in a year but greater precipitation amounts and intensities per storm. In other words, an increase in the frequency of extreme events is expected.

Based on the results of this study, NT management reduced runoff and erosion in Piedmont soils. Compared with CT, NT reduced runoff by 33%. NT maintained soil loss rates below the tolerable level at all times averaging 2.6 Mg ha^{-1} y^{-1} (1.1 tn ac^{-1} yr^{-1}) compared with CT where soil loss during the six-year study period was 448.2 Mg ha^{-1} (199.9 tn ac^{-1}) of which 397.3 Mg ha^{-1} (177.2 tn ac^{-1}) (89%) was lost during the three months having multiple storms of high intensity rainfall. The average soil loss rate in CT was almost 11 times the tolerable level at 74.7 Mg ha^{-1} y^{-1} (33.3 tn ac^{-1}).

In general, for the Mecklenburg sandy clay loam and Enon clay loam of the southeastern Piedmont, NT management was an effective management technique for reducing erosion compared to CT. The demonstrated added

Table 1
Percent water stable aggregates in conventional tillage and no-tillage.

Soil depth	Tillage treatment within each soil depth: Conventional tillage	No-tillage
0 to 2.5 cm	34.3a	44.4b
2.5 to 5.0 cm	33.4a	41.2b
5.0 to 7.5 cm	25.3a	38.1b
7.5 to 15 cm	28.5a	31.1a
15 to 30 cm	16.4a	13.4a

Note: Tillage treatment means having the same letters in common are not significantly different at the 5% probability level as indicated by Fisher's Protected LSD test.

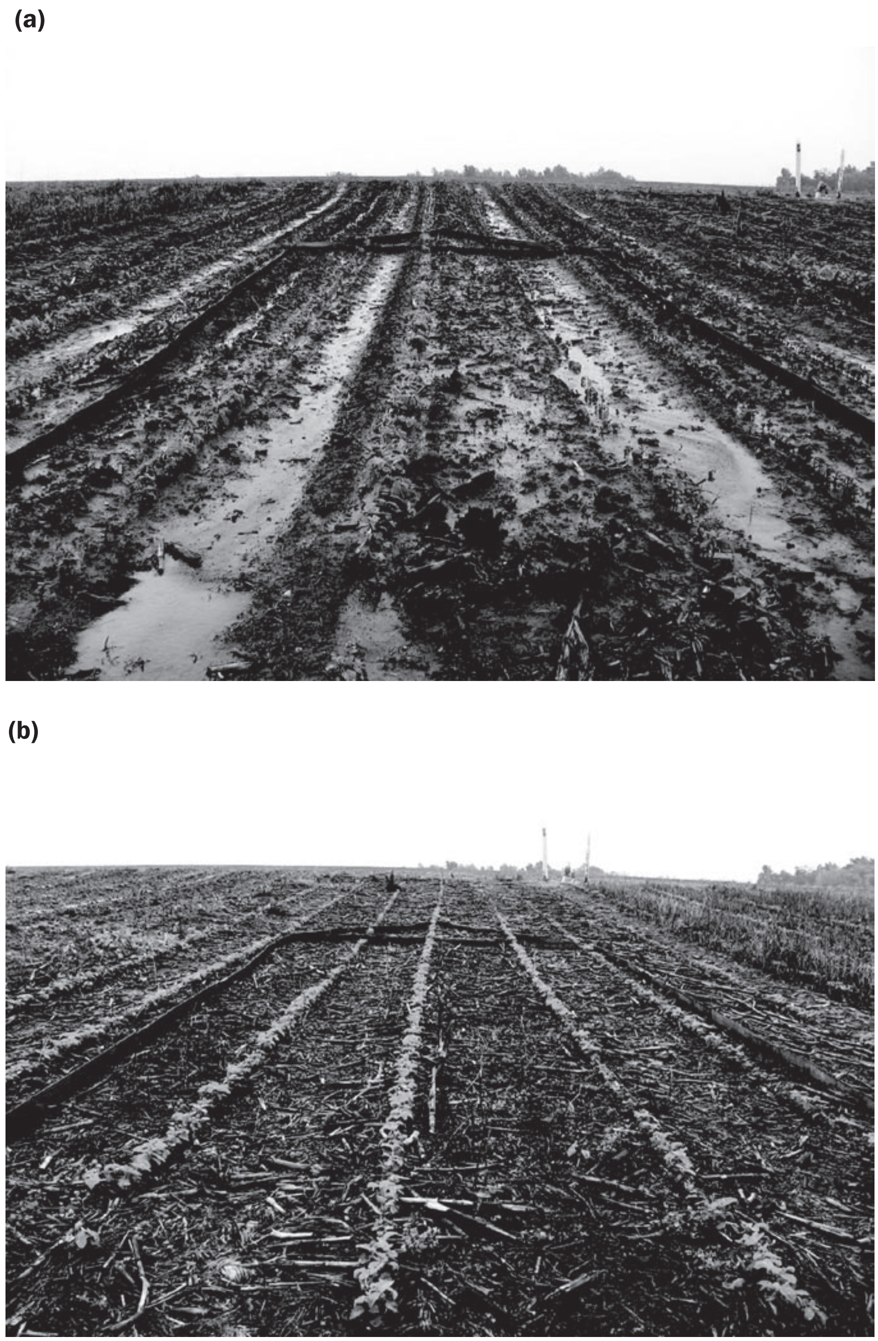
Table 2
Rainfall intensity characteristics of storms occurring between July 22 and July 29, 1997.

Storm date	Total rainfall (mm)	Rainfall intensity	Percent of total rainfall: <40 mm hr^{-1}	40 to 80 mm hr^{-1}	80 to 120 mm hr^{-1}	>120 mm hr^{-1}
July 22	116		12%	37%	28%	23
July 23	40		57%	43%	0%	0%
July 24	13		100%	0%	0%	0%
July 25	7		100%	0%	0%	0%
July 29	67		3%	14%	0%	83%
Total*	243		24%	29%	13%	34%

* Rainfall intensity percentages in this row are percentages of the total rainfall amount (243 mm).

Note: Data are the percentage of the total rainfall amount that fell at the listed intensity.

Figure 5
Photos taken on June 12, 2001, of (a) conventional tillage and (b) no-tillage plots during a light-intensity rain and immediately after 38 mm of rainfall.

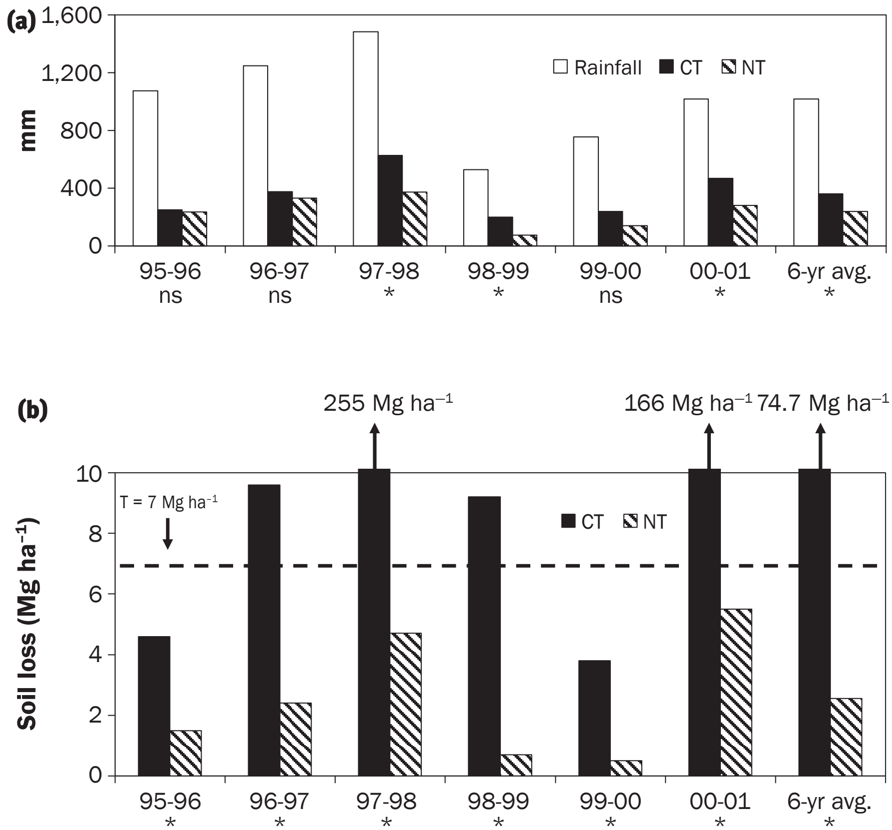


Notes: The conventional tillage photo shows an almost completely sealed soil surface, the occurrence of runoff (see free water on the soil surface), and zones with washed sediment in wheel-traffic areas. The no-tillage photo shows a soil surface almost entirely covered by crop residue and no evidence of wash or runoff.

benefits of increased infiltration and better soil quality with NT may help farmers break their traditional habit of CT. This is needed for the region to maintain acceptable levels of crop productivity.

Figure 6

Yearly runoff totals (a) and soil loss totals (b) in conventional tillage (CT) and no tillage (NT) treatments; 1995 to 1996 = 95 to 96, 1996 to 1997 = 96 to 97, 1997 to 1998 = 97 to 98, 1998 to 1999 = 98 to 99, 1999 to 2000 = 99 to 00, 2000 to 2001 = 00 to 01.



Note: For each year, a significant difference (p = 0.05) between CT and NT treatment means is denoted as "*" while nonsignificance is indicated as "ns."

Table 3

Height of soil lost in months having extreme storm events.

	No-tillage		
Parameter*	**July 1997**	**June 2000**	**Sept. 2000**
Bulk density (Mg m^{-3})	1.48	1.52	1.51
Soil loss (Mg ha^{-1})	2.5	2.3	1.1
Soil loss (cm)	1.7×10^{-2}	1.5×10^{-2}	0.7×10^{-2}
Total soil height lost (cm = 0.04)			
	Conventional tillage		
Parameter	**July 1997**	**June 2000**	**Sept. 2000**
Bulk density (Mg m^{-3})	1.37	1.35	1.40
Soil loss (Mg ha^{-1})	241.8	92.9	62.6
Soil loss (cm)	1.76	68.8×10^{-2}	44.7×10^{-2}
Total soil height lost (cm = 2.90)			

* The analysis of variance for each parameter showed a significant difference (p < 0.05) between no-tillage and conventional tillage on each date.

Note: This loss was calculated by using the listed values of soil bulk density, determined from core samples collected from the upper 7. 5 cm prior to each storm period.

Acknowledgements

The authors would like to acknowledge the assistance provided by Leon Moses, North Carolina A&T State University Farm superintendent, in the design and installation of runoff collectors and erosion plots, and in conducting all the necessary farming operations required during the six-year study period. Most of the funding for this research was supplied by the USDA Cooperative State Research, Education, and Extension Service (Project NCX-185-5-04-130-1, Agricultural Research Program, North Carolina A&T State University). We would also like to thank Lane Price (assistant state conservationist, USDA Natural Resources Conservation Service, Raleigh, North Carolina) and Bobby Brock (state agronomist, USDA Natural Resources Conservation Service, Raleigh, NC) for giving us the opportunity to obtain Environmental Quality Incentives Program funding for this research.

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